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TESTS OF VARIOUS ALIPHATIC COMPOUNDS AS FUMIGANTS

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INTRODUCTION

The action of several organic compounds in the vapor phase upon rice weevils, flour beetles, granary weevils, and the Indian-meal moth was tested in a previous investigation,[1] and the results were reported in Department Bulletin 1313. The object of that investigation was to find a material free from the fire hazard of carbon disulphide that would be suitable for killing insects in grain. When the tests were made in glass flasks about 30 of the 100 compounds tested were more toxic to the rice weevil than was carbon disulphide. In tests made when grain was present, especially in box cars loaded with wheat, only ethyl acetate and ethyl formate gave uniformly good results, and because of its lower cost and greater availability the acetate was considered preferable to the formate. A mixture of 40 volumes of ethyl acetate and 60 volumes of carbon tetrachloride was recommended as a fumigant safe from fire hazard at fumigating temperatures, that is, up to 90° F.

In order to make ethyl acetate nonflammable at temperatures up to 122° F. (50° C.), however, the temperature at which the underwriters' laboratories conduct tests to determine whether a vapor will propagate a flame, it is necessary to add carbon tetrachloride to the

[1] NEIFERT, I. E., COOK, F. C., ROARK, R. C., TONKIN, W. H., BACK, E. A., and COTTON, R. T. FUMIGATION AGAINST GRAIN WEEVILS WITH VARIOUS VOLATILE ORGANIC COMPOUNDS. U. S. Dept. Agr. Bul. 1313, 40 p., illus. 1925.

extent of 70 per cent by volume of the mixture. Ethyl acetate has only a moderate toxicity to insects exposed to its vapor, and the addition of carbon tetrachloride, which has a low toxicity to insects, produces a mixture having an insecticidal value lower than that of ethyl acetate alone.

Furthermore, wheat that has been fumigated with the ethyl acetate mixture may have a sour odor, resulting from acetic acid formed by hydrolysis of the ethyl acetate. This odor is similar to that of fermenting grain, and sometimes causes the wheat to be classed as Sample grade.

The experiments herewith reported were conducted in order to develop effective fumigants more suitable for treating infested grain, and for use in fumigating against insects infesting foodstuffs, clothing, carpets, and furniture. Some of the compounds previously investigated and many additional organic compounds were thoroughly tested.

TESTS IN ONE-HALF LITER FLASKS

METHOD

In order to select the more promising fumigants from the large number of compounds to be tested, an initial series of tests was made in ½-liter Erlenmeyer flasks. By fumigating on a small scale it was possible to make 30 or 40 fumigations in a day and thus test possible fumigants more quickly than if trials were made on a large scale. On account of its resistance to fumigants the rice weevil (*Sitophilus oryza* L.) was used exclusively in these small-scale tests. The weevils were confined in cotton-stoppered glass vials containing cracked corn, 10 weevils to each vial. One, or in some cases two, of the vials were placed on the bottom of a ½-liter Erlenmeyer flask, 200 grams (approximately 250 c. c.) of wheat was put in, and the calculated quantity of fumigant was added. The flasks were made airtight with rubber stoppers and allowed to stand 24 hours at room temperature, which averaged about 25° C. At the end of the 24-hour fumigation period the percentage of dead weevils was determined. To avoid reporting as dead any that were only stupefied, all specimens were reexamined after 24 hours and also after 48 hours. Many specimens were kept for 30 days after fumigation, but none revived after the 48-hour period. The percentage of dead weevils reported in Table 1 is that determined at the end of the 48-hour period.

This series of experiments differs from that reported in Department Bulletin No. 1313, in that all the fumigants were tested in the presence of wheat. Inasmuch as under practical fumigating conditions absorptive materials are always present, it was believed that tests in the presence of wheat, which has a great absorptive capacity for some vapors, would determine fumigants of low toxicity more quickly than if the tests were made in flasks containing no absorptive material.

The compounds selected for testing were obtained for the most part from the Eastman Kodak Co. A few materials were synthesized in the laboratory. In all cases, compounds of the highest possible purity procurable were used for these tests.

The liquid fumigants were applied by means of a pipette graduated to 0.01 c. c. The dosages are therefore known within 0.02 cubic centimeter per liter, which is equivalent to about 13 mg. per liter

(0.8 pound per 1,000 cubic feet) for a material of low specific gravity, such as *n*-pentane; or to about 66 mg. per liter (4 pounds per 1,000 cubic feet) for a material of high specific gravity, such as methylene iodide. The solid fumigants were weighed to the nearest milligram and added to the flasks. In general, in this series of tests, where the minimum lethal dosage of the fumigant was determined to within 0.01 c. c. per ½-liter flask, the results are accurate to within about 2 pounds per 1,000 cubic feet. For a more exact determination of the minimum lethal dosage of a fumigant, tests on a larger scale are necessary.

Each fumigant was tested from 5 to 30 times over a range of different concentrations. No fumigant was tested at a concentration of more than 0.5 c. c. per liter. Some fumigants killed 100 per cent of the weevils at the minimum dosage it was possible to employ, 0.02 c. c. per liter. In other cases many dosages were tried, and the minimum that killed 100 per cent of the weevils during an exposure of 24 hours was taken as the minimum lethal dosage.

As some fumigants were tested in quantities varying by 0.05 c. c. per ½-liter flask, the lethal dosage of these compounds is not known closer than 0.10 c. c. per liter. Only compounds of low toxicity, however, were tested in this way, as the object of this first series of tests was to select the fumigants worthy of trial on a large scale, rather than to determine the exact minimum lethal dosage of the compounds.

EXPERIMENTAL RESULTS

The results of the tests are given in Table 1, which presents in addition the following information regarding each fumigant: Empirical and structural formulas, synonyms, molecular weight, boiling point,[2] specific gravity,[2] concentration of fumigant, expressed in milligrams per liter, and percentage mortality of weevils after 24 hours' exposure.

[2] Data taken from NATIONAL RESEARCH COUNCIL. INTERNATIONAL CRITICAL TABLES OF NUMERICAL DATA, PHYSICS, CHEMISTRY AND TECHNOLOGY . . . v. 1, 415 p., illus., New York and London, 1926.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 76 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
C_5H_{12}	Pentane	$CH_3CH_2CH_2CH_2CH_3$	72.096	36.2	0.631	[1] 316	40
	(Mixture; largely *n*-pentane)						
	Amyl hydride						
	Pentan						
	Normales pentan						
	n-Pentan						
C_6H_{14}	*n*-Hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$	86.108	69.0	.660	[1] 330	60
	Dipropyl						
	Hexan						
	Normales hexan						
	n-Hexan						
C_7H_{16}	*n*-Heptane	$CH_3(CH_2)_5CH_3$	100.12	98.4	.684	260	100
	Heptyl hydride						
	Methyl hexane						
	Dipropylmethane						
	Heptan						
	Normales heptan						
	n-Heptan						
C_8H_{18}	*n*-Octane	$CH_3(CH_2)_6CH_3$	114.144	124.6	.707	[1] 354	60
	Octan						
	Normales octan						
	n-Octan						
$C_{10}H_{22}$	Decane	$(CH_3)_2CH(CH_2)_4CH(CH_3)_2$	142.176	160.0	.722	[1] 361	6
	2, 7-Dimethyloctane						
	Diisoamyl						
	2.7-Dimethyl-octan						
C_5H_{10}	Amylene		70.077		.7	[1] 350	0
	Mixture of:						
	*Iso*propylethylene	$(CH_3)_2CHCH=CH_2$		20.2			
	Trimethylethylene	$(CH_3)_2C=CHCH_3$		38.4			
	as-Methylethylethylene	$CH_2=C(CH_3)C_2H_5$		31–33			
	2-Pentene	$CH_3CH_2CH=CHCH_3$		36			
	*Iso*pentane	$(CH_3)_2CHCH_2CH_3$		28			
	Käufliches Amylen						
	Gewöhnliches Fuselölamylen						
C_5H_{10}	Trimethylethylene	$(CH_3)_2C=CHCH_3$	70.077	38.4	.668	[1] 334	40
	2-Methyl-2-butene						
	Pental						

	Pentene Amylene β-*Isoamylene* 2-Methyl-buten-(2) Trimethyl-Äthylen β-Methyl-β-butylene						
C_8H_{16}	Octylene		112.12	125	.7197	[1] 360	70
	Caprylene Mixture of: α-Octylene (Octene-(1))	$CH_3(CH_2)_5CH=CH_2$					
	β-Octylene (Octene-(2))	$CH_3(CH_2)_4CH=CH\ CH_3$					
	Octylen Caprylen Mixture of: Octen-(1) α-Octylen Octen-(2) β-Octylen						
C_8H_{16}	Diisobutylene	$(CH_3)_3CCH=C(CH_3)_2$	112.12	102.6	.715	215	100
	Diisobutylen						
CH_2Br_2	Methylene bromide	CH_2Br_2	173.86	97.8	2.46	738	100
	Dibromomethane Dibrommethan Methylenbromid						
$CHBr_3$	Bromoform	$CHBr_3$	252.76	150.4	2.89	231	100
	Tribromomethane Methenylbromide Formyl tribromide Methenyl tribromide Tribrommethan Methenylbromid						
CBr_4	Carbon tetrabromide	CBr_4	331.66	189.5	3.43	60	100
	Tetrabromomethane Tetrabrommethan Kohlenstofftetrabromid Tetrabromkohlenstoff						
C_2H_5Br	Ethyl bromide	CH_3CH_2Br	108.955	38.0	1.43	172	100
	Bromoethane Monobromoethane Hydrobromic ether Bromic ether Brom-äthan Äthylbromid						
$C_2H_4Br_2$	Ethylidene bromide	CH_3CHBr_2	187.86	110	2.056	617	100
	1, 1-Dibromoethane 1, 1-Dibrom-äthan Äthylidenbromid						
$C_2H_4Br_2$	Ethylene dibromide	CH_2BrCH_2Br	187.86	131.7	2.182	87	100
	1, 2-Dibromoethane Ethylene bromide Dibromoethane 1, 2-Dibrom-äthan						

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
$C_2H_4Br_2$	Ethylene dibromide—Continued Äthylendibromid Äthylenbromid					*Mg. per liter*	*Per cent*
$C_2H_2Br_4$	*sym.*-Tetrabromoethane 1, 1, 2, 2-Tetrabromoethane Acetylene tetrabromide Muthmann's liquid 1. 1. 2. 2-Tetrabrom-äthan Acetylentetrabromid	$CHBr_2CHBr_2$	345.68	°C. 151 (54 mm.)	2.964	[1] 1,482	0
C_3H_7Br	*n*-Propyl bromide 1-Bromopropane 1-Brom-propan α-Brom-propan *n*-Propylbromid *prim.*-Propylbromid	$CH_3CH_2CH_2Br$	122.97	70.9	1.353	81	100
C_3H_7Br	*Iso*propyl bromide 2-Bromopropane 2-Brom-propan β-Brom-propan *Iso*propylbromid *sek.*-Propylbromid	$(CH_3)_2CHBr$	122.97	59.6	1.316	262	100
$C_3H_6Br_2$	Propylene bromide 1, 2-Dibromopropane Propylene dibromide 1, 2-Dibrom-propan Propylendibromid Propylenbromid	$CH_3CHBrCH_2Br$	201.88	140	1.933	116	100
C_4H_9Br	*n*-Butyl bromide 1-Bromobutane 1-Brom-butan *n*-Butylbromid *prim.*-Butylbromid	$CH_3CH_2CH_2CH_2Br$	136.99	101.6	1.275	102	100
C_4H_9Br	*Iso*butyl bromide 1-Bromo-2-methylpropane α-Bromo-*iso*butane 1-Brom-2-methylpropan α-Brom-*iso*butan *Iso*butylbromid	$(CH_3)_2CHCH_2Br$	136.99	91.5	1.264	126	100

C_4H_9Br	*sec.*-Butyl bromide 2-Bromobutane 2-Brom-butan *sek.*-Butylbromid	$CH_3CHBrCH_2CH_3$	136.99	91.3	1.251	375	100
C_4H_9Br	*tert.*-Butyl bromide 2-Bromo-2-methylpropane β-Bromo-*iso*butane 2-Brom-2-methylpropan β-Brom-*iso*butan *tert.*-Butylbromid	$(CH_3)_3CBr$	136.99	73.3	1.222	[1] 24	100
$C_4H_8Br_2$	α-Butylene bromide 1, 2-Dibromobutane α-Butylene dibromide 1, 2-Dibrom-butan α-Butylendibromid	$CH_3CH_2CHBrCH_2Br$	215.89	166	1.820	[1] 910	80
$C_4H_8Br_2$	β-Butylene bromide 2, 3-Dibromobutane β-Butylene dibromide Pseudobutylene dibromide 2, 3-Dibrom-butan β-Butylendibromid Pseudobutylendibromid	$CH_3CHBrCHBrCH_3$	215.89	158	1.83	[1] 915	80
$C_4H_8Br_2$	*Iso*butylene bromide 1, 2-Dibromo-2-methylpropane $\alpha\beta$-Dibromo-*iso*butane Butylene *iso*bromide Dibromo*iso*butane 1, 2-Dibrom-2-methylpropan $\alpha\beta$-Dibrom-*iso*butan *Iso*butylendibromid	$CH_3CBr(CH_3)CH_2Br$	215.89	149	1.759	281	100
$C_4H_7Br_3$	1, 2, 3-Tribromobutane 1. 2. 3-Tribrom-butan	$CH_2CHBrCHBrCH_2Br$	294.80	113 (19 mm.)	2.190	[1] 1,095	0
$C_5H_{11}Br$	*Iso*amyl bromide 4-Bromo-2-methylbutane 4-Brom-2-methylbutan *Iso*amylbromid	$(CH_3)_2CHCH_2CH_2Br$	151	121	1.215	146	100
C_3H_5Br	Allyl bromide 3-Bromopropylene 3-Bromopropene 3-Brom-propen-(1) Allylbromid	$CH_2=CHCH_2Br$	120.965	71.3	1.398	[2] 28	100
CH_2Cl_2	Methylene chloride Dichloromethane Methylene bichloride Dichlormethan Methylenchlorid	CH_2Cl_2	84.931	40.1	1.336	426	100
$CHCl_3$	Chloroform Trichloromethane Methenyl chloride Trichlormethan Methenylchlorid	$CHCl_3$	119.38	61.2	1.489	298	100

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
CCl_4	Carbon tetrachloride Tetrachloromethane Perchloromethane Tetrachlormethan Kohlenstofftetrachlorid Tetrachlorkohlenstoff	CCl_4	153.83	76.8	1.595	638	100
$C_2H_4Cl_2$	Ethylidene chloride 1, 1-Dichloroethane 1, 1-Dichlor-äthan Äthylidenchlorid	CH_3CHCl_2	98.947	57.3	1.174	564	100
$C_2H_4Cl_2$	Ethylene dichloride 1, 2-Dichloroethane Ethylene chloride Elayl chloride Oil of the Dutch chemists Dichloroethane Dutch liquid 1, 2-Dichlor-äthan Äthylendichlorid Äthylenchlorid Ölder holländischen chemiker Elaylchlorid	$CH_2Cl–CH_2Cl$	98.947	83.7	1.257	226	100
C_2H_4BrCl	Ethylene chlorobromide 1-Bromo-2-chloroethane 2-Chlor-1-Brom-äthan Äthylenchlorobromid	$CH_2Br–CH_2Cl$	143.405	103.7	1.79	143	100
$C_2H_3Cl_3$	Trichloroethane 1, 1, 2-Trichloroethane Ethylene monochlorochloride Monochloroethylene chloride Monochlorinated Dutch liquid Vinyltrichloride 1, 1, 2-Trichlor-äthan	$CH_2ClCHCl_2$	133.397	113.5	1.443	404	100
$C_2H_2Cl_4$	*sym.*-Tetrachloroethane 1, 1, 2, 2-Tetrachloroethane Acetylene tetrachloride	$CHCl_2CHCl_2$	167.85	146.3	1.600	384	100

	Tetrachloroethane 1. 1. 2. 2-Tetrachlor-äthan Acetylentetrachlorid						
C_2HCl_3	Pentachloroethane	$CHCl_2CCl_3$	202. 298	162	1. 709	542	100
	Pentachlor-äthan						
C_2Cl_6	Hexachloroethane	CCl_3CCl_3	236. 75	185	2. 093	1 500	0
	Perchloroethane Carbon trichloride Carbon hexachloride Tetrachloroethylene dichloride Hexachlor-äthan Perchloräthan						
C_3H_7Cl	*n*-Propylchloride	$CH_3CH_2CH_2Cl$	78. 512	46. 6	. 890	445	100
	1-Chloropropane α-Chloropropane 1-Chlor-propan α-Chlor-propan Propylchlorid						
C_3H_7Cl	*Iso*propyl chloride	$CH_3CHClCH_3$	78. 512	36. 5	. 860	430	100
	2-Chloropropane β-Chloropropane 2-Chlor-propan β-Chlor-propan *Iso*propylchlorid						
$C_3H_6Cl_2$	Propylene chloride	$CH_3CHClCH_2Cl$	112. 962	96. 8	1. 166	140	100
	1, 2-Dichloropropane Propylene dichlorides α-β-Dichloropropane 1. 2-Dichlor-propan α β-Dichlor-propan Propylendichlorid Propylenchlorid						
$C_3H_6Cl_2$	Trimethylene chloride	$ClCH_2CH_2CH_2Cl$	112. 962	125	1. 201	336	100
	1, 3-Dichloropropane Trimethylene dichloride 1. 3-Dichlor-propan α γ (oder ω.ω′-) Dichlor-propan Trimethylendichlorid Trimethylenchlorid						
C_4H_9Cl	*n*-Butyl chloride	$CH_3CH_2CH_2CH_2Cl$	92. 527	78	. 884	265	100
	1-Chlorobutane 1-Chlor-butan *n*-Butylchlorid *prim.*-Butylchlorid						
C_4H_9Cl	*tert.*-Butyl chloride	$(CH_3)_3CCl$	92. 527	51	. 840	34	100
	2-Chloro-2-methylpropane β-Chlor-*iso*butane 2-Chlor-2-methylpropan β-Chlor-*iso*butan *tert.*-Butylchlorid Trimethylchlormethan						

[1] The maximum dosage tested.

77459°—30——2

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				°C.		*Mg. per liter*	*Per cent*
C_4H_9Cl	*n*-Butylidene chloride 1, 1-Dichlorobutane 1. 1-Dichlor-butan Butylidenchlorid	$CH_3CH_2CH_2CHCl_2$	126. 98	113–115	1. 1	220	100
$C_5H_{11}Cl$	*Iso*amyl chloride 4-Chloro-2-methylbutane 4-Chlor-2-methylbutan *Iso*amylchlorid	$(CH_3)_2CHCH_2CH_2Cl$	106. 54	99. 1	. 893	167	100
$C_2H_2Cl_2$	Dichloroethylene 1, 2-Dichloroethene Acetylene dichloride $\alpha\beta$-Dichloroethylene 1.2-Dichlor-äthen *sym.*-oder $\alpha\beta$-Dichlor-äthylen Acetylen-dichlorid	$CHCl=CHCl$	96. 931	[1] 55	1. 25	600	100
C_2HCl_3	Trichloroethylene Trichlor-äthan Trichlor-äthylen	$CHCl=CCl_2$	131. 38	88	1. 477	650	100
C_2Cl_4	Tetrachloroethylene Tetrachloroethene Perchlorethylene Carbon bichloride Carbon dichloride Tetrachlor-äthen Tetrachlor-äthylen Perchloräthylen	$Cl_2C=CCl_2$	165. 83	120. 8	1. 623	649	100
CH_3I	Methyl iodide Iodomethane Jodmethan Methyljodid	CH_3I	141. 96	42. 6	2. 279	[1] 46	100
CH_2I_2	Methylene iodide Diiodomethane Dijodmethan Methylenjodid	CH_2I_2	267. 88	[1] 180	3. 325	[1] 67	100
CHI_3	Iodoform Triiodomethane Methenyl iodide	CHI_3	393. 80	(4)	4. 1	[1] 500	0

	[illegible]						
C_2H_5I	Ethyl iodide [illegible]	CH_3CH_2I	155.97	72.3	1.933	[1] [illegible]	[illegible]
C_3H_7I	n-Propyl iodide [illegible]	$CH_3CH_2CH_2I$	169.99	102.4	1.747	[1] [illegible]	[illegible]
C_3H_7I	Isopropyl iodide [illegible]	$(CH_3)_2CHI$	169.99	[illegible]	1.703	[illegible]	[illegible]
C_4H_9I	n-Butyl iodide [illegible]	$CH_3CH_2CH_2CH_2I$	184.00	127	1.617	97	100
C_4H_9I	Isobutyl iodide [illegible]	$(CH_3)_2CHCH_2I$	184	120.4	1.606	64	100
C_4H_9I	sec-Butyl iodide [illegible]	$CH_3CHICH_2CH_3$	184	117.5	1.595	64	100
C_4H_9I	tert-Butyl iodide [illegible]	$(CH_3)_3CI$	184	98-99	1.570	[illegible]	100

[1] The maximum dosage tested.

[2] The minimum concentration tested.

[3] Boiling point [illegible] mm., [illegible].

[4] [illegible]

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity at 20° C.	Mg. per liter	Weevil mortality after exposure for 24 hours
				°C.		Mg. per liter	Per cent
$C_4H_{11}I$	Isobutyl iodide	$(CH_3)_2CHCH_2CH_2I$	198.02	148.0	1.595	110	100
	4-Iodo-2-methylbutane						
	4-Iodo-2-methylbutane						
	Isobutyl iodide						
C_3H_5I	Allyl iodide	$CH_2=CHCH_2I$	167.97	103.1	1.849	1.37	100
	3-Iodopropene-1						
	3-Iodopropene						
	1-Iodopropene-2						
	3-Iodopropene-(1)						
	3-Iodo-1-propene						
	Allyl iodide						
CH_4O	Methyl alcohol	CH_3OH	32.031	64.5	.792	1.305	0
	Methanol						
	Carbinol						
	Wood alcohol						
	Wood spirit						
	Wood naphtha						
	Methyl hydroxide						
	Methyl hydrate						
	Columbian spirits						
	Colonial spirit						
	Monohydrol						
	Hydroxide						
C_2H_6O	Ethyl alcohol	CH_3CH_2OH	46.046	78.3	.789	1.730	40
	Ethanol						
	Grain alcohol						
	Fermentation alcohol						
	Cologne spirit						
	Spirits of wine						
	Alkanol						
	Ethyl hydroxide						
	Wine alcohol						
C_3H_8O	n-Propyl alcohol	$CH_3CH_2CH_2OH$	60.062	97.8	.804	1.402	80
	1-Propanol						
	Ethyl carbinol						
	Propyl alcohol						
	Propanol-1						

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentrations of fumigants, and percentage mortality of insects after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 25°/4°	Vapor density (weight of 1 liter of fumigant in grams)	Concentration of fumigant in air (by volume)
				°C.		Mg. per liter	
$C_4H_{10}O$	n-Butyl alcohol	$CH_3CH_2CH_2CH_2OH$	88.082	117.5	0.817	4.0	Per cent
	1-Butanol						
	Butyric alcohol						
	1-Hydroxybutane						
	n-Propylcarbinol						
	Butyl alcohol						
	Propylmethanol						
	1-Butyric alcohol						
$C_4H_{10}O$	Isobutyl alcohol	$(CH_3)_2CHCH_2CH_2OH$	88.082	108.3	.812	30	100
	2-Methyl-1-propanol						
	Isobutanol						
	Isopropylcarbinol						
	Dimethylethylcarbinol						
	Isobutyl alcohol						
	1-Propanol, 2-methyl-						
	Isobutyric alcohol						
	2-Methylpropanol-(1)						
	Isobutanol						
$C_4H_{10}O$	sec-Butyl alcohol	$CH_3CH(OH)CH_2CH_2CH_3$	88.082	99.5	808	304	100
	2-Butanol						
	Methylethylcarbinol						
	Diethylcarbinol						
	β-Butyl alcohol						
	Methyl-n-propylcarbinol						
	sec-Monohydroxybutane						
$C_4H_{10}O$	Diethyl carbinol	$(C_2H_5)_2CHOH$	88.082	115.6	.833	320	100
	3-Pentanol						
	Pentanol-(3)						
	γ-Ethyl propanol						
	Diethylhydroxymethane						
$C_4H_{10}O$	tert-Amyl alcohol	$(CH_3)_2C(OH)CH_2CH_3$	88.082	102.5	.809	42	100
	2-Methyl-2-butanol						
	Dimethylethylcarbinol						
	Amylene hydrate						
	2-Methylbutanol-(2)						
	Dimethyl ethyl carbinol						
	tert-Amylalcohol						
	Amylenhydrat						

Cabbage										
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[1] The exposure [illegible]

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound and synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity at 4°	Concentration of fumigant	Mortality of adult weevils
				°C.		Mg. per liter	Per cent
$C_8H_{16}O$	2-n-Octyl alcohol	$CH_3CH(OH)CH_2CH_2CH_2CH_2CH_2CH_3$	130.24	178.3	0.819	[illegible]	[illegible]
	[illegible]						
$C_7H_{16}O$	n-Heptyl alcohol	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2OH$	116.21	175	0.824	1.64	0
	[illegible]						
C_3H_6O	Allyl alcohol	$CH_2=CHCH_2OH$	58.08	96.9	0.855	1.1	28
	[illegible]						
$C_3H_6Br_2O$	[illegible]	$CH_2BrCHBrCH_2OH$	153.86	219.4	2.087	3.0	28
	[illegible]						
C_3H_5ClO	Epichlorohydrin	CH_2OCHCH_2Cl	92.53	116.8	1.181	2.3	28
	[illegible]						

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of [illegible], and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point	Specific gravity	[illegible]	Mortality
C_2H_4O	[illegible]	[illegible]	44.05	[illegible]	[illegible]	[illegible]	[illegible]
C_3H_6O	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_4H_9BrO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] Dichloroether [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$C_3H_8O_2$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$C_4H_{10}O_2$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$C_6H_{14}O_2$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$C_4H_{10}O_2$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

C_2H_2O	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_2H_4O	[illegible]	CH_3CHO	44.031	20.2	[illegible]	10
C_3H_6O	[illegible]	CH_3COCH_3	[illegible]	[illegible]	[illegible]	0
C_4H_8O	[illegible]	$CH_3CH_2CH_2CHO$	[illegible]	[illegible]	[illegible]	0
$C_5H_{10}O$	Methyl propanal 2-Oxo-3-methyl-propan [illegible]	[illegible]	[illegible]	61	[illegible]	100
$C_6H_{12}O$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$C_7H_{14}O$	Heptaldehyde	$C_6H_{13}CHO$	114.11	153	.820	0
$C_8H_{16}O_2$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2 2 2 Trichlor Ethanol (1)
Trichloracetic aldehyde

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formulas, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity at 4° C.	Mortality [illegible] fumigant in milligrams per liter	Mortality [illegible] fumigant in milligrams per liter
C_3H_4O	Acrolein Propenal	$CH_2=CHCHO$	56.031	°C. 52.5	0.841	Mg. per liter 100	Per cent 100
$C_4H_{10}O$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_4H_6O	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_4H_8O	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_4H_6O	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_4H_8O	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE OF VALUES ARRANGED ACCORDING TO MOLECULAR

$C_6H_{10}O$		$CH_2=CHCH_2CH_2COCH_3$	98.08	128.1	0.85	0	0
$C_6H_{10}O_2$		$CH_3COOC_4H_7$	114.08	127.5	0.91	0	0
$C_6H_{12}O$		$CH_3COCH_2CH(CH_3)_2$	100.09	119	.803	64	100
$C_6H_{12}O_2$		$C_4H_9COOCH_3$	116.09	102.5	.903	19	100
$C_6H_{12}O$		$CH_3COC_4H_9$	114.11	150	.822	320	100
$C_6H_{12}O$		$C_4H_9COC_2H_5$	142.14	173	.827	1 410	0
$C_6H_{12}O$		$C_4H_9COC_2H_5$	170.17	226.3	.826	1 412	0
$C_6H_{12}O_2$			88.105	101	0.905	14	100
C_6H_{14}			86.11	69	.664	16	0
$C_6H_{14}O$			86.109	91	.811	148	0
$C_6H_{14}O$			86.109	121	.819	148	100

1 The maximum is quite sharp.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigant, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound and synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity	Minimum lethal concentration of fumigant	Weevils killed after exposure for 24 hours
				°C.		*Mg. per liter*	*Per cent*
$C_2H_2O_3$	Formic acid	HCOOH	46.02	100.7	1.220	1,000	0
	Methanol						
	Acetaldehyde						
	Ethylene oxide						
	Acetic acid and methyl formate						
$C_2H_4O_2$	Acetic acid	CH_3COOH	60.03	118.1	1.049	1,000	0
	Allylamine						
	Methan carboxylate						
	Propylene						
	Acetone aldehyde						
	Ethyl nitrite-acetaldehyde						
	Formic acid						
$C_2H_2Cl_2O_2$	Chloroacetic acid	$CH_2ClCOOH$	94.48	189.3	1.368	1,000	0
	Dichloroethanol						
	Glycolchlorohydrin						
	Glycol chlorohydrin						
$C_2H_2Cl_2O_2$	Dichloroacetic acid	$CHCl_2COOH$	128.94	192.5	1.563	1,000	0
	Chloroacetic acid						
	Acetaldehyde chloride						
	Acetaldehyde dichloride						
	Vinyl chloride acetic acid						
	Monochloroacetic acid						
	Ethylidene chloride acid						
$C_2H_2Cl_3O_2$	Trichloroacetic acid	CCl_3COOH	163.39	196.5	1.634	1,000	0
	Chloroacetic acid						
	Propionic acid trichloride						
	Acetaldehyde chloride						
	Acetaldehyde dichloride						
	Ethylidene chloride acid						
	Ethylene chloride acid						
	Trichloroacetic acid						
$C_6H_5O_2$	Benzoic acid	C_6H_5COOH	122.05	249.2	1.316	1,000	0
	Phenylformic acid						
	Benzene carboxylic acid						
	Dracylic acid						
	Benzenecarboxylic acid						

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigant, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity at 20°, 4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				°C.		Gm. per liter	Per cent
$C_2H_2O_4$	[illegible]	$(COOH)_2$	126.016	64	1.653	1.744	50
$C_2H_4O_2$	Methyl formate	$HCOOCH_3$	60.031	31.8	.975	39	100
$C_3H_6O_2$	[illegible]	$HCOOC_2H_5$	74.046	54.3	.936	72	100
$C_4H_8O_2$	n-[illegible]	$HCOOC_3H_7$	88.062	81.3	.901	72	100
$C_4H_8O_2$	[illegible]	$HCOOCH(CH_3)_2$	88.062	71.3	.883	53	100
$C_5H_{10}O_2$	n-[illegible]	$HCOOC_4H_9$	102.08	106.8	.911	109	100
$C_5H_{10}O_2$	[illegible]	$HCOOCH_2CH(CH_3)_2$	102.08	98.2	.878	33	100
$C_7H_{14}O_4$	[illegible]	$HC(OC_2H_5)_3$	148.12	145.9	.897	90	100
$C_6H_{12}O_2$	[illegible]	$HCOOCH_2CH_2CH(CH_3)_2$	116.09	123.3	.871	70	100
$C_3H_4O_2$	[illegible]	$HCOOCH_2CH=CH_2$	86.046	83	.948	28	100
$C_2H_3ClO_2$	Methyl [illegible]	$ClCOOCH_3$	94.481	71.4	1.226	104	100
$C_3H_5ClO_2$	Ethyl [illegible]	$ClCOOC_2H_5$	108.497	93	1.138	261	100

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigant, and percentage mortality of insects after exposure for 24 hours*—Continued

Empirical formula	Fumigant and synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity at 20° C.	Minimum dosage of fumigant	Weevils killed after exposure for 24 hours
				°C.		*Mg. per liter*	*Per cent*
$C_4H_6O_3$			102.05	170	1.42	1,000	0
$C_4H_7BrO_2$			167.02	157–158	1.5	1,000	90
$C_5H_{10}BrO_2$			181.04	76 (37 mm.)	1.324	1,000	100
$C_5H_9ClO_2$			136.58	146	1.156	67	100
$C_5H_9BrO_2$			181.04		1.4	1,000	0
$C_6H_{11}BrO_2$			195.06		1.3	1,000	100
$C_6H_{11}BrO_2$			195.06	165	1.354	1,000	100
$C_7H_{14}O_2$			130.10	150	1.0	75	100
$C_6H_{11}ClO_2$			150.5	163	1.146	61	100
$C_6H_{11}ClO_2$			150.59	158.5	1.45	1,000	100
$C_6H_{11}ClO_2$			150.59	160.5	1.06	95	100
$C_6H_{11}ClO_2$		$CH_3CHClCOOCH_2CH_2CH_2CH_3$	150.594	175	1.060	210	100
$C_6H_{11}ClO_2$			150.59	160.5	1.060	210	100
$C_6H_{11}IO_2$			242.06	198	1.603	1,000	100
$C_6H_{11}BrO_2$	Ethyl α-bromopropionate		195.06	148	1.419	95	100
$C_6H_{11}BrO_2$			195.06	150 (50 mm.)	1.4	1,000	0
$C_5H_9ClO_3$			152.58	167.5	1.179	1,000	90

Ethyl β-bromopropionate
2-bromopropanoic acid (1) ethylester
β-Brompropionsäureäthylester
Ethyl 2-chloropropionate
Ethyl α-chloropropionate

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigant, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Chemical name or synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity at 20°/4°	Concentration of fumigant to kill 50 percent of adult weevils	Mortality of weevils after exposure for 24 hours
$C_6H_{12}O_2$	[illegible]	$C_4H_9COOCH_3$	116.12	[illegible]	[illegible]	[illegible]	[illegible]
$C_6H_{12}O_2$	[illegible]	$CH_3CH(CH_3)CH_2COOCH_3$	116.12	[illegible]	0.898	[illegible]	[illegible]
$C_6H_{12}O_2$	[illegible]	$CH_3CH_2CH(CH_3)COOCH_3$	116.12	[illegible]	[illegible]	[illegible]	[illegible]
$C_6H_{12}O_2$	[illegible]	$CH_3CH_2CH_2CH_2COOCH_3$	116.12	[illegible]	[illegible]	[illegible]	[illegible]
$C_6H_{12}O_2$	[illegible]	$C_6H_{13}CH_2OCH_2CH_2OCH_3$	132.18	[illegible]	[illegible]	[illegible]	[illegible]
$C_6H_{12}O_2$	[illegible]	$C_6H_{13}CH_2OCH_2CH_2OH$	132.18	[illegible]	[illegible]	[illegible]	[illegible]
$C_6H_{12}O_2$	[illegible]	$CH_3COOC_6H_{11}$	142.11	[illegible]	0.969	[illegible]	[illegible]
	Cyclohexyl acetate						
	Diethyl acetal of acetaldehyde						
	Diisopropyl ether of ethylene glycol						
	Methyl n-hexanoate						
$C_6H_{12}O_2$	[illegible]	$C_5H_{11}COOCH_3$	116.12	[illegible]	[illegible]	[illegible]	c
	Allyl n-butyrate						
	Ethyl isobutyrate						
	Ethyl n-propionate						
	Isopropyl acetate						
	n-Propyl acetate						
$C_6H_{12}O_2$	[illegible]	$CH_3CH_2COOC_2H_5$	102.09	[illegible]	[illegible]	[illegible]	[illegible]
	Diethyl acetal of acetaldehyde						
	Diisopropyl ether						
	Ethyl propionate						
$C_6H_{12}O_2$	[illegible]	$CH_3CH_2CH_2COOCH_3$	102.09	[illegible]	[illegible]	[illegible]	[illegible]
	Isopropyl acetate						
	Methyl n-butyrate						
	n-Propyl acetate						
$C_6H_{12}O_2$	[illegible]	$CH_3CH_2CH_2CH_2COOH$	116.12	[illegible]	[illegible]	[illegible]	[illegible]
	Diethyl acetal of acetaldehyde						
	Isobutyl acetate						
	n-Butyl acetate						
	sec-Butyl acetate						
$C_6H_{12}O_2$	[illegible]	$(CH_3)_2CHCH_2COOCH_3$	116.12	[illegible]	[illegible]	[illegible]	[illegible]
	Methyl isobutyrate						

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	265	.968	¹ 454	0
[illegible]	[illegible]	[illegible]	[illegible]	88.7	1.069	¹ 535	90
[illegible]	[illegible]	[illegible]	[illegible]	121.5	.979	286?	100
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

¹ The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigant, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound and its synonyms	Structural formula	Molecular wt.	Boiling point at 760 mm.	Specific gravity at 20° C.	Mean lethal concentration of fumigant	Percentage mortality in the check
C_3H_5N	*Isocyanoethylene* 2-Propenenitrile β-Cyanoethylene Vinyl cyanide	$CH_2{=}CHCH{\equiv}N$	53.07	77.3°	0.806	0.5 per cent	1%
C_3H_5N	*n*-Propylamine 1-Aminopropane α-Aminopropane Propyl amine Propanamine (8CI) (9CI) Monoaminopropane	$CH_3CH_2CH_2NH_2$	59.09	49	0.80	0.5 per cent	0
C_3H_6ClN	*Isopropyl chloramine* 1-Chloro-2-aminopropane α-Chloro-β-aminopropane Chloro-2-propylamine	$(CH_3)_2CHCl{\cdot}NH_2$	91.54	68	0.98	0.5 per cent	0
C_3H_7N	*sec*-Propylamine 2-Aminopropane β-Aminopropane Methylethylamine (obsolete) *sec*-Propylamine (8CI) Isopropylamine	$CH_3CHNHCH_3$	59.09	33	0.69	0.5 per cent	0
C_3H_9N	*n*-Amylamine 1-Aminopentane α-Aminopentane Pentylamine (8CI) *n*-Aminopentane	$CH_3CH_2CH_2CH_2CH_2NH_2$	87.14	104	0.76	0.5 per cent	0
C_3H_9N	*Isoamylamine* 3-Aminopentane or methyl-3-butylamine β-Aminoisopentane or isopentylamine Isopentylamine (8CI) Isoamylamine	$CH_3CH(CH_3)CH_2CH_2NH_2$	87.14	95	0.75	0.5 per cent	0
C_3H_9N	Allylamine 2-Aminopropene-(1) γ-Aminopropylene Allylamine	$CH_2{=}CHCH_2NH_2$	57.08	53.3	0.76	0.5 per cent	0
C_3H_9N	Dimethylamine (2 per cent in water) Dimethylamine	$(CH_3)_2NH$	45.08	7.4	0.68	0.5 per cent	0

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.711	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.738	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.722	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.74	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.745	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.767	[illegible]	[illegible]
[illegible]	[illegible]	$(CH_2{=}CHCH_2)_2NH$	97.16	[illegible]	.73	[illegible]	[illegible]
[illegible]	[illegible]	$(CH_3)_3N$	59.077	[illegible]	.662	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.728	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.757	[illegible]	[illegible]
[illegible]	[illegible] Tributylamin	[illegible]	[illegible]	[illegible]	.770	[illegible]	[illegible]
$C_{15}H_{33}N$	Triisoamylamine [illegible]	$(C_5H_{11})_3N$	227.26	[illegible]	.785	[illegible]	[illegible]
[illegible]	[illegible] Tetramethylammoniumhydroxid	[illegible]	[illegible]	[illegible]	....	[illegible]	[illegible]
C_2H_3N	Acetonitrile Methyl cyanide Ethannitril Acetonitril Methylcyanid	CH_3CN	41.031	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	$CH_3CH_2CH_2CN$	69.062	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	$CH_3CH_2CH_2CH_2CN$	83.077	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The maximum dosage tested.

[illegible]

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigant, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity	Concentration of fumigant	Percentage mortality of adult weevils after exposure for 24 hours
				°C.		*Mg. per liter*	*per cent*
C_3H_3ClO	Chloroacetone	$ClCH_2COCH_3$	92.50	119	1.150	100	0
$C_3H_3ClO_2$	2,3-Epoxypropyl chloride; epichlorohydrin	$ClCH_2CHOCH_2$	92.50	116	1.180	100	0
$C_3H_4Cl_2$	Dichloropropene	$ClCH_2CH=CHCl$	110.97	96	1.217	100	0
$C_3H_4Cl_2$	1,2-Dichloropropane	$CH_3CHClCH_2Cl$	112.98	96.8	1.156	100	0
$C_3H_4Cl_2$	1,3-Dichloropropene	$ClCH_2CH=CHCl$	112.98	112	1.217	100	0
$C_3H_5ClO_2$	3-Chloro-1,2-propanediol; alpha-monochlorohydrin; glycerol alpha-monochlorohydrin	$ClCH_2CH(OH)CH_2OH$	110.52	213	1.322	100	0
$C_3H_5NO_3$	Isopropyl nitrate	$(CH_3)_2CHONO_2$	105.08	101	1.026	100	0
	Isopropyl ester of nitrous acid; isopropyl nitrite	$(CH_3)_2CHONO$	89.08	39	0.872	100	0
	Nitroethane	$CH_3CH_2NO_2$	75.07	114.8	1.052	100	0
$C_3H_5NO_3$	2-Nitro-1-propanol	$CH_3CH(NO_2)CH_2OH$	105.08	132	1.203	100	0
	1-Nitro-2-propanol	$CH_3CH(OH)CH_2NO_2$	105.08	92	1.203	100	0
$C_3H_5NO_3$	Isopropyl nitrite	$(CH_3)_2CHONO$	103.08	39	0.872	100	0
	Isoamyl ester of nitrous acid; isoamyl nitrite	$(CH_3)_2CHCH_2CH_2ONO$	117.10	97	0.877	100	0
	Amyl nitrite	$CH_3(CH_2)_3CH_2ONO$	117.10	96	0.902	100	0
$C_3H_6Cl_2$	Dichloropropane	$CH_2ClCH_2CH_2Cl$	112.98	96	1.159	100	0
	Allyl chloride; 3-chloropropene	$CH_2=CHCH_2Cl$	76.53	45	0.938	100	0
	Propylene dichloride; 1,2-dichloropropane	$CH_3CHClCH_2Cl$	112.98	96.8	1.156	100	0
$C_3H_6Cl_2$	1,3-Dichloropropene	$ClCH_2CH=CHCl$	112.98	112	1.217	100	0
	2,3-Dichloropropene	$CH_2=CClCH_2Cl$	112.98	94	1.214	100	0
$C_3H_6Cl_2$	1,2-Dichloropropane	$CH_3CHClCH_2Cl$	112.98	96.8	1.156	100	0
	1,3-Dichloropropene	$ClCH_2CH=CHCl$	112.98	112	1.217	100	0
C_3H_6O	Propylene oxide; methyloxirane	CH_3CHOCH_2	58.08	35	0.830	100	0
	Allyl alcohol; 2-propen-1-ol	$CH_2=CHCH_2OH$	58.08	96.9	0.855	100	0
	Propionaldehyde; propanal	CH_3CH_2CHO	58.08	49	0.807	100	0
$C_3H_6O_2$	Methyl acetate	CH_3COOCH_3	74.08	57	0.934	100	0
	Ethyl formate	$HCOOC_2H_5$	74.08	54	0.923	100	0
	Propionic acid; ethylformic acid	CH_3CH_2COOH	74.08	141	0.992	100	0
$C_3H_6O_3$	Glycerol formal; 4-hydroxymethyl-1,3-dioxolane	$CH_2(OH)CHOCH_2OCH_2$	90.08	193	1.315	100	0
	Dihydroxyacetone; 1,3-dihydroxy-2-propanone	$CH_2(OH)COCH_2OH$	90.08	138	1.320	100	0
C_3H_7ClO	Propylene chlorohydrin; 1-chloro-2-propanol	$CH_3CH(OH)CH_2Cl$	94.53	127	1.119	100	0
	Trimethylene chlorohydrin; 3-chloro-1-propanol	$ClCH_2CH_2CH_2OH$	94.53	161	1.197	100	0
C_3H_7NO	Propionamide	$CH_3CH_2CONH_2$	73.09	213	1.052	100	0
	Lactamide; 2-hydroxypropionamide	$CH_3CH(OH)CONH_2$	89.09	120	1.232	100	0
$C_3H_7NO_2$	Ethyl carbamate; urethane	$NH_2COOC_2H_5$	89.09	184	0.986	100	0
	Alanine; 2-aminopropionic acid	$CH_3CH(NH_2)COOH$	89.09	212	1.401	100	0
$C_3H_7NO_3$	Nitroisopropanol; 2-nitro-1-propanol	$CH_3CH(NO_2)CH_2OH$	105.08	132	1.203	100	0
	Nitroethylcarbinol; 1-nitro-2-propanol	$CH_3CH(OH)CH_2NO_2$	105.08	92	1.203	100	0
C_3H_8O	Isopropyl alcohol; 2-propanol	$(CH_3)_2CHOH$	60.10	82.4	0.789	100	0
	Propyl alcohol; 1-propanol	$CH_3CH_2CH_2OH$	60.10	97	0.804	100	0
C_3H_8O	Methyl ether; dimethyl oxide	CH_3OCH_3	46.07	−24	0.661	100	0
	Ethyl alcohol; ethanol	CH_3CH_2OH	46.07	78	0.789	100	0

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity at 20° C.	Mortality of adult weevils exposed for 24 hours at 20° C.	Concentration of fumigant in grams per liter of space
C_4H_3NS	Thiazole 1,3-Thiazole Thiophene monothia Thiophene, 1-aza-3-thia- Thiophene, 3-aza-1-thia- Isothiazole	C_4H_3NS	97.112	116.5° C.	1.201	100 percent in 1 hour	2.50 grams
C_4H_3NS	2-Thiazolamine 2-Thiazolylamine 2-Aminothiazole Thiazole, 2-amino-	$C_3H_2(NH_2)NS$	99.112	140.7°	1.44	100	10
$C_4H_4O_2S$	Ethylene sulfite Ethylene glycol sulfite Dioxathiolane 1,3,2-Dioxathiolane, 2-oxide Dioxathiolane oxide Glycol sulfite	$C_2H_4O_3S$	132.14	173.5	1.477	100	10
$C_4H_8O_4S$	Methionine hydroxy 2-Hydroxy-4-methylthiobutyric acid Methionine, hydroxy analog 2-Hydroxy-4-(methylthio)-butanoic acid	$C_5H_{12}O_3S$	152.111	286.5	1.318	90	5.0

[1] The maximum concentration tested.

DISCUSSION OF RESULTS

In considering the results of the fumigation tests upon weevils in ½-liter glass flasks, it should be borne in mind that the tests were conducted in the presence of a relatively large quantity of wheat, which has a large absorptive capacity for the vapors of many compounds. The minimum lethal dosage is greater, therefore, than if no wheat were present.

The exact minimum lethal concentration of compounds in the vapor phase would have to be determined in the absence of wheat or any other absorptive material, and under carefully controlled conditions of temperature and humidity, and to compare the toxicity of compounds accurately the concentration of vapor should be expressed in terms of gram-molecules per liter, or molar percentage. The minimum lethal dose of each compound as determined in these tests, however, includes the true minimum lethal concentration of vapor plus the quantity of material absorbed by the wheat plus the quantity that failed to volatilize. The tests in this series were made for the sole purpose of rapidly surveying the field of possible fumigants suitable for the destruction of insects in grain, but it is believed that the following information obtained on the relations between the chemical-physical properties of organic compounds and their toxicity to rice weevils is of value.

On account of the experimental error of the tests, results within 20 per cent of each other are rated as equal.

RELATIVE TOXICITY OF THE ALIPHATIC COMPOUNDS TESTED

Hydrocarbons

Of nine hydrocarbons tested, only two, *n*-heptane and dimethallyl, killed all the weevils, and even these were not highly toxic. Aliphatic hydrocarbons of the methane or ethylene series do not appear promising as grain fumigants.

Bromides

Under the conditions of the test the order of toxicity of the bromine substitution products of hydrocarbons is as follows:

Of methane, carbon tetra[illegible]>methylene bromide.
Of ethane, ethylene>ethyl>ethylidene.
Of propane, *n*-propyl>1, 2-dibromo>isopropyl.
Of butane, [illegible]>butyl>[illegible]>isobutyl.
Of the straight chain bromides, *n*-propyl=*n*-butyl>ethyl.

The alkylene radical appears to be more toxic than the corresponding alkyl one; for example, the toxicity of allyl bromide is greater than that of *n*-propyl bromide.

Two of the bromides, *tert.*-butyl and allyl bromides, killed 100 per cent of the weevils at the minimum[4] dosage tried.

Tetrabromomethane, 1, 2-dibromobutane, 2, 3-dibromobutane, and 1, 2, 3-tribromobutane did not kill all the weevils at the maximum[4] dosage tried.

[4] The minimum dosage of each compound tested was 0.02 c. c. per liter.
[4] [illegible] dosage of each compound tested was 0.50 c. c. per liter.

Chlorides

The order of toxicity of the chlorine substituted hydrocarbons is as follows:

Of methane, chloroform > methylene chloride > carbon tetrachloride.
Of ethane, ethylene dichloride > pentachloroethane > ethylidene chloride > hexachloroethane.
Of propane, 1, 2-dichloropropane > 1, 3-dichloro-n-propyl.
Of butane, sec.-butyl > 1, 4-dichloro-n-butyl.
Of ethene, dichloro- > trichloro- > tetrachloro.

The following relations are also significant:

*Iso*amyl > *n*-butyl > *n*-propyl.
1, 2-Dichloroethane > 1, 1-dichloroethane.
Trichloroethane > trichloroethene.
Tetrachloroethane > tetrachloroethene.

Only one aliphatic chloride tested, hexachloroethane, failed to kill 100 per cent of the weevils at the maximum dosage used.

Iodides

Five of the twelve aliphatic iodides tested killed all weevils at the minimum dosage tried. Iodoform was the only iodide that did not kill all weevils at the maximum dosage tested.

The comparative toxicity of the iodides is as follows:

n-Propyl > *iso*propyl.
*Iso*butyl = *sec.*-butyl > *n*-butyl.
n-Propyl > *n*-butyl > *iso*amyl.

In toxicity to weevils, chlorides, bromides, and iodides rank as follows:

COMPARATIVE TOXICITY OF CHLORIDES, BROMIDES, AND IODIDES

Substitution product of—	Derivative	Order of toxicity
Methane	Di	Iodide > bromide > chloride.
	Tri	
	Tetra	
Ethane	Mono	Iodide > bromide > chloride.
	1, 1-Di	bromide = chloride.
	1, 2-Di	
Propane	Mono-1	Iodide > bromide > chloride.
	Mono-2	Iodide > bromide > chloride.
	1, 2-Di	bromide > chloride.
Butane	*n*-Butyl	Iodide > bromide > chloride.
	*Iso*butyl	Iodide > bromide.
	sec.-Butyl	Iodide > bromide.
	tert.-Butyl	bromide > chloride.
Pentane	*Iso*amyl	Chloride > bromide = iodide.

Ethylene dibromide > ethylene chlorobromide > ethylene dichloride.

Alcohols

Twenty-four alcohols were tested. Ten, namely, methyl, ethyl, *n*-propyl, *n*-butyl, *n*-amyl, *n*-hexyl, *n*-heptyl, di-*n*-propyl carbinol, *n*-octyl, and *n*-nonyl alcohols, failed to kill all the weevils at the maximum dosage tried. The order of toxicity of the other alcohols is as follows:

tert.-Amyl = methylbutylcarbinol = dimethyl *n*-propyl carbinol > *tert.*-butyl > triethylcarbinol > *iso*butyl = *sec.*-butyl = *sec.*-butyl-

[illegible]

Some of the straight chain primary alcohols were effective in killing weevils. The branched chain primary alcohols [illegible] were effective, but less so than the secondary and tertiary alcohols with the same number of carbon atoms. Of the 5 most toxic alcohols, 4 are tertiary, and 1 is a secondary alcohol.

The following orders of toxicity were ascertained:

*Iso*propyl > *n*-propyl
tert.-Butyl > isobutyl > *sec.*-butyl > *n*-butyl
tert.-Amyl > *sec.*-butylcarbinol > isoamyl > *sec.*-amyl > diethylcarbinol > *n*-amyl.
Methylbutylcarbinol > dimethyl-*n*-propylcarbinol > *n*-hexyl
[illegible]
sec.-Octyl > *n*-octyl.
Allyl > isopropyl > *n*-propyl.
Primary alcohols, isobutyl > *sec.*-butylcarbinol > isoamyl.
Secondary alcohols, methylbutylcarbinol > *sec.*-butyl > *sec.*-octyl > *sec.*-amyl > diethylcarbinol > isopropyl.
Tertiary alcohols, *tert.*-Amyl > dimethyl-*n*-propylcarbinol > triethylcarbinol.

Halogen Substituted Alcohols

The comparative toxicity of the halogen substituted alcohols is as follows:

Epichlorohydrin > [illegible] > ethylene [illegible] > methylene bromohydrin > trimethylene chlorohydrin or trichloro *tert.*-butyl alcohol.

Epichlorohydrin was effective at the minimum dosage used, but trimethylene chlorohydrin and trichloro-*tert.*-butyl alcohol failed to kill all weevils even at the rate of 0.40 c. c. per liter. The substitution of chlorine or bromine for hydrogen in ethyl and *n*-propyl alcohols resulted in an increase in their toxicity to weevils mixed with wheat.

Amino Alcohols

β-Dimethylamino ethyl alcohol, the only amino alcohol tested, failed to kill all weevils when applied at the rate of 0.20 c. c. per liter.

Ethers

As a class, the ethers were weak in insecticidal action. Of 11 tested, 8 failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter. The toxicity of the others may be compared as follows:

Di-*n*-propyl > methyl-*n*-amyl > ethyl-*n*-butyl > [illegible] > methyl-*n*-butyl
Di-*n*-propyl > diisopropyl.

There is no constant relation between the toxicity of the ethers and their corresponding alcohols. For example,

*Iso*propyl alcohol > diisopropyl ether, but
n-propyl ether > *n*-propyl alcohol.

Oxides

The two oxides tested were highly toxic to weevils in wheat. Ethylene oxide has such a high vapor pressure at room temperature (25° C.) that it was difficult accurately to pipette small quantities of it. Its exact toxic dosage is shown by the tests in the 500-cubic-foot fumigating vault, p. 49.

Halogen Substituted Ethers

Of five halogen substituted ethers tested, two, 2-bromoethyl ethyl ether and 2-chloroethyl ether, killed at the minimum dosage tried. Chloromethyl methyl ether failed to kill all weevils at the maximum dosage, and the dichloromethyl ether had low toxicity.

The position of the substituting halogen atoms affects the toxicity of the compound. For example, 2-chloroethyl ether is much more toxic than 1, 2-dichloroethyl ethyl ether.

Acetals

Ethylal, acetal, and dimethylacetal are about equally toxic, the minimum lethal dosage of each being 340 mg. per liter. Methylal failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter.

Aldehydes

Formaldehyde, applied as the aqueous solution formalin, propionaldehyde, *n*-butyraldehyde, isovaleraldehyde, and heptaldehyde failed to kill all weevils at the maximum dosage.

Isobutyraldehyde is the most toxic of the aldehydes tested.

The following relations were determined:

Isobutyraldehyde>propionaldehyde>*n*-butyraldehyde.
Acrolein>propionaldehyde.
Acrolein>crotonaldehyde.

Ketones

The order of toxicity of the ketones follows:

Dipropyl ketone>diethyl ketone>dimethyl ketone.
Di-*n*-butyl and di-*n*-amyl ketones did not kill all weevils at the dosage of 0.50 c. c. per liter.
Methyl isobutyl ketone>methyl *n*-butyl ketone>methyl *n*-propyl ketone>methyl *n*-amyl ketone>ethyl methyl ketone>dimethyl ketone.

Of all the ketones tested, mesityl oxide is the most toxic to weevils in wheat.

One of the two diketones tried, diacetyl, failed to kill all weevils at the maximum dosage.

Acids

Not one of the nine acids tested killed any weevils at the maximum dosage of 0.50 c. c. per liter. The vapors of these acids appear to be taken up by wheat and thus fail to reach the weevils underneath.

Acid Chlorides and Bromides

Nine compounds of the acid chloride and bromide class killed no weevils when tested in a dosage of 0.50 c. c. per liter. Wheat appears to retain the vapors of these compounds in the same manner that it does those of the acids.

Esters

Formates

The order of toxicity of the formates is as follows:

Methyl>ethyl>isopropyl>*n*-propyl>isoamyl>*n*-amyl>*n*-butyl.
Ethyl orthoformate is slightly less toxic than ethyl formate.

CHLOROFORMATES

Nine chloroformate compounds were tested. Methyl chloroformate was found to be more toxic than ethyl chloroformate, and this in turn was more toxic than *n*-propyl chloroformate.

2-Chloroethyl chloroformate is less toxic than ethyl chloroformate.

Six chloroformates failed to kill all weevils in wheat even at the maximum dosage.

ACETATES

Ten esters of acetic acid were tried. Two, namely, *n*-heptyl and *sec*-octyl acetates, failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter. The order of toxicity of the others is:

Isobutyl = *n*-propyl > *sec*-octyl = [illegible] > [illegible] = methyl = ethyl = *n*-butyl.

HALOGENATED ESTERS OF ACETIC ACID

Bromomethyl and 3-bromopropyl acetates did not kill all the weevils at the maximum dosage. 2-Bromoethyl acetate killed 100 per cent of the weevils at the minimum dosage applied. The toxicity of 2-bromomethyl is greater than that of 2-chloroethyl.

ESTERS OF HALOGENATED ACETIC AND PROPIONIC ACIDS

The following are the orders of toxicity found for the esters of halogenated acetic and propionic acids:

Methyl bromoacetate >methyl chloroacetate.
Ethyl bromoacetate >ethyl chloroacetate.
Methyl chloroacetate >ethyl chloroacetate >*n*-butyl chloroacetate.
Ethyl chloroacetate >ethyl dichloroacetate >ethyl trichloroacetate.
Ethyl 2-bromopropionate >ethyl 2-bromopropionate.
Ethyl bromoacetate>ethyl 2-bromopropionate.

CYANOACETATES

The only ester of cyanoacetic acid tried, ethyl cyanoacetate, failed to kill 100 per cent of the weevils at the maximum dosage.

PROPIONATES

Among the propionates the following order of toxicity was observed:

Ethyl=*n*-propyl>methyl=*iso*butyl>*iso*amyl.

n-Butyl propionate failed to kill all weevils at the maximum dosage.

LACTATES

Two esters of lactic (α-hydroxypropionic acid) were tested, methyl and ethyl. Both proved ineffective at the maximum concentration of 0.50 c.c. per liter.

n-BUTYRATES

Four esters of *n*-butyric acid, *n*-propyl, *n*-butyl, isobutyl, and isoamyl, failed to kill all weevils at the maximum dosage used. Of the other two, the toxicity of the methyl is greater than that of the ethyl.

ISOBUTYRATES

Two esters of isobutyric acid were tested. The ethyl is more toxic than the *iso*butyl.

n-VALERATES

The methyl ester was the only *n*-valerate that gave a 100 per cent kill. Ethyl and *n*-butyl *n*-valerates were ineffective.

ISOVALERATES

The ethyl ester was effective, but the *n*-propyl, isobutyl, and isoamyl esters failed to kill at the maximum dosage of 0.50 c. c. per liter.

CAPROATES, HEPTYLATES, AND CAPRYLATES

None of the methyl and ethyl esters of the caproic, heptylic, and caprylic acids killed 100 per cent of the weevils at the maximum dosage of 0.50 c. c. per liter.

OXALATES

Neither the dimethyl, diethyl, nor diisoamyl esters killed any weevils even at the maximum dosage.

CARBONATES

Six esters of carbonic acid were tested. Only the diethyl ester gave a 100 per cent kill.

DIACETATE AND ACETOACETATE

Ethylidene diacetate and ethyl acetoacetate were ineffective.

ACRYLATE

The only ester of an unsaturated acid that was tried, ethyl β-β dimethyl acrylate, was effective at a dosage of 2.08 mg. per liter.

COMPARISON OF TOXICITY OF METHYL, ETHYL, AND ISOBUTYL ESTERS

The relative toxicity of the methyl, ethyl, and isobutyl esters of different fatty acids is shown in Table 2, which gives the minimum lethal dosage of each.

TABLE 2.—*Toxicity of methyl, ethyl, and isobutyl esters of various fatty acids to rice weevils learned in advance*

Acid	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—			Acid	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—		
	Methyl ester	Ethyl ester	Isobutyl ester		Methyl ester	Ethyl ester	Isobutyl ester
	Mg.	Mg.	Mg.		Mg.	Mg.	Mg.
Formic	40	1	17	Tiglic	200	100	100
Acetic	50	50	67	Undecylenic	(1)	(1)	(1)
Propionic	50	100	134	Oleic	(1)	(1)	(1)
n-Butyric	50	84	67	Linoleic	(1)	(1)	(1)
Isobutyric	(1)	67	200	Linolenic	(1)	(1)	(1)

[illegible] (mg. per liter) [illegible] 100 per cent of the weevils.
[illegible] tested.

From the data in Table 2 it is evident that the esters of formic acid are markedly more toxic to weevils in wheat than are the esters of the higher acids.

The esters of the branched chain acids are more toxic than those of the corresponding straight chain acids having the same number of carbon atoms. For example,

Ethyl isobutyrate > ethyl n-butyrate.
*Iso*butyl isobutyrate > isobutyl n-butyrate.
Ethyl isovalerate > ethyl n-valerate.

Effect of Halogen Substitution in Esters

IN THE ACID RADICAL

The esters of chloroformic acid are decidedly less toxic to weevils covered with wheat than are the corresponding esters of formic acid. This is attributed to the great instability of the chloroformates. Apparently most of their vapors are absorbed by the wheat before they come in contact with the weevils. For instance,

Methyl formate > methyl chloroformate.
Ethyl formate > ethyl chloroformate.

The introduction of a single chlorine or bromine atom in acetic acid greatly increases the toxicity of the esters. For example,

Methyl chloroacetate > methyl acetate.
Ethyl chloroacetate > ethyl acetate.

The introduction of two or three chlorine atoms in acetic acid, however, decreases the toxicity of the esters. In that case the following is the order of toxicity:

Ethyl chloroacetate > ethyl acetate > ethyl dichloroacetate > ethyl trichloroacetate.

The introduction of a single bromine atom in the alpha position into propionic acid increases the toxicity of the ethyl ester, but in the beta position decreases the toxicity.

Ethyl 2-bromopropionate > ethyl propionate > ethyl 3-bromopropionate

IN THE ALKYL RADICAL

No consistent relations in toxicity seem to hold when halogen is substituted in the alkyl radical.

Methyl acetate > bromomethyl acetate.
Propyl acetate > 3-bromopropyl acetate, but
2-Bromo- and 2-chloroethyl acetates > ethyl acetate.

The following comparison shows this inconsistency:

2-Chloroethyl acetate > ethyl chloroacetate, but
Methyl bromoacetate > bromomethyl acetate.

Amines

PRIMARY AMINES

None of the primary amines exhibits much toxicity to weevils in wheat. The following comparisons were made:

*Iso*propyl > n-propyl.
sec.-Butyl > isobutyl > n-butyl.
*Iso*amyl > n-amyl.

Four out of ten primary amines failed to kill all weevils when applied at the rate of 0.50 c. c. per liter.

SECONDARY AMINES

The following order of toxicity of the secondary amines was observed:

Diisopropyl>di-2-n-propylethanol>diallyl.
Diisobutyl>di-n-butyl.

TERTIARY AMINES

Three out of five tertiary amines tested, namely, trimethyl, tri n-butyl, and triisopropylamines, failed to kill all the weevils. Triethyl and tri n-propylamines are about equally toxic.

QUATERNARY AMINES

The only quaternary ammonium derivative tested, tetramethylammonium hydroxide, failed to kill any weevils in wheat at the maximum dosage of 0.50 c. c. per liter.

COMPARISON OF PRIMARY, SECONDARY, AND TERTIARY AMINES

An exact comparison of the amines can not be made, because so many tested failed to kill 100 per cent of the weevils. The toxicity of diethylamine, however, is greater than that of triethylamine, which in turn is greater than the toxicity of monoethylamine. In general, the secondary amines appear to be more toxic than the primary or tertiary amines.

NITRILES

The nitriles are toxic in the following order:

*Iso*capro>*n*-valero=propio=*n*-butyro.

Acetonitrile was not effective in killing 100 per cent of the weevils in wheat at the maximum dosage.

Chloral cyanohydrin and cyanuric acid killed no weevils at the maximum dosage.

NITRO COMPOUNDS, NITRITES, NITRATES, OXIMES, AND HYDROXYLAMINES

In toxicity the nitro compounds, nitrites, nitrates, oximes, and hydroxylamines rank as follows:

Nitroethane>Nitromethane.
n-Butyl nitrite=*iso*amyl nitrite.
*Iso*amyl nitrate>ethyl nitrate.
*Iso*amyl nitrite>*iso*amyl nitrate.

Diacetyl monoxime and n-methylhydroxylamine are about equally toxic, the minimum lethal dosage of each being 90 mg. per liter.

MERCAPTANS

As a class, the mercaptans are extremely toxic. Ethyl mercaptan killed all the weevils in wheat at the minimum dosage tried, 0.02 c. c. per liter. The order of toxicity of the mercaptans is as follows:

Ethyl>isobutyl>n-propyl>n-butyl>isoamyl>isopropyl.

As shown in Table 3, the mercaptans are much more toxic to weevils in wheat than are the corresponding alcohols.

TABLE 5.—*Toxicity of mercaptans and sulphides to rice weevils [text illegible]*

Radical	Minimum lethal dosage [illegible]		Radical	Minimum lethal dosage [illegible]	
	Mercaptan	Sulphide		Disulphide	Selenide
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
n-Propyl	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
*Iso*propyl	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Not tested.
[2] Given in the cubic centimetre, [illegible]
[3] Maximum dosage tried.

Sulphides

The comparative toxicity of the sulphides is as follows:

n-Propyl>*iso*butyl>ethyl=methyl>allyl.

The sulphides are distinctly less toxic to weevils in wheat than are the corresponding mercaptans. For example,

Ethyl mercaptan (17)[1]>diethyl sulphide (419).[2]
n-Propyl mercaptan (48)[1]>dipropyl sulphide (244).[2]
*Iso*butyl mercaptan (33)[1]>diisobutyl sulphide (334).[2]

Disulphides

Only two disulphides were tested, methyl and ethyl. The methyl is more toxic than the ethyl.

The disulphides are much more toxic than the sulphides, but somewhat less toxic than the mercaptans. For example,

Methyl disulphide>methyl sulphide.
Ethyl mercaptan>ethyl disulphide>ethyl sulphide.

Selenides

The only selenide tested, ethyl selenide, was more toxic than the corresponding sulphide, ethyl sulphide.

Miscellaneous Sulphur Compounds

Butanesulphochloride, dimethyltrithiocarbonate, and mercapital did not kill all weevils at the maximum dosage of [illegible] per liter.

The other sulphur compounds tested, namely, thioacetic acid, thionyl chloride, and perchloromethyl mercaptan, were only slightly to moderately toxic to weevils in wheat.

Thio- and *Iso*thiocyanates

The following order of toxicity exists among the thiocyanates:

*Iso*propyl>methyl>ethyl.

[1] Minimum dosage tried.
[2] Minimum lethal dosage

The isothiocyanates are more toxic than the corresponding thiocyanates, ethyl isothiocyanate, for instance, being more toxic than ethyl thiocyanate.

Ethyl and allyl isothiocyanates killed all weevils at the minimum dosage.

Sulphites and Sulphates

Ethyl sulphite, the only sulphite tried, was more toxic to weevils in wheat than was methyl sulphate, the one sulphate tested.

Comparative Toxicity of Alkyls

The difference in toxicity of the methyl, ethyl, and *n*-propyl derivatives is, in general, so slight that the results of the tests are not sufficiently accurate to establish the proper order of toxicity. Furthermore, these tests were made on a basis of milligrams per liter rather than milligram molecules per liter. It was noticed, however, that the *n*-propyl derivative is more toxic than the isopropyl derivative in the bromide, chloride, iodide, ether, acetate, and mercaptan, whereas the *iso*propyl derivative is more toxic in the alcohol, formate, primary amine, and secondary amine.

The general order of toxicity of the butyl derivatives is as follows:

tert.-Butyl>*iso*butyl=*sec.*-butyl>*n*-butyl.

Every *tert.*-butyl derivative tested (bromide, chloride, and alcohol) was more toxic than the corresponding *n*- and *sec.*-butyl derivatives.

The *iso*butyl derivative is more toxic than the *n*-butyl in the iodide, alcohol, aldehyde, ketone (methyl isobutyl ketone>methyl *n*-butyl ketone), formate, acetate, propionate, primary amine, secondary amine, and mercaptan. *n*-Butyl and isobutyl bromides are almost equally toxic.

The unsaturated radical, allyl, appears to have more toxicity than the *n*-propyl radical.

The allyl is more toxic than the *n*-propyl in the bromide, alcohol, aldehyde, and formate, but *n*-propyl sulphide is more toxic than allyl sulphide.

Most Effective Fumigants

The fumigants shown in these tests to be the most effective are grouped in the following list:

Part 1.—Fumigants Lethal in the Minimum Dosage Applied (0.02 c. c. per Liter)

	Mg per liter		Mg per liter
Ethyl mercaptan	Less than 17	Allyl bromide	Less than 28
Isopropyl thiocyanate	do 19	2-Bromoethyl acetate	do 30
Ethyl thiocyanate	do 20	Methyl bromoacetate	do 30
Allyl isothiocyanate	do 20	Ethyl bromoacetate	do 30
Methyl disulphide	do 21	*n*-Propyl iodide	do 35
tert.-Butyl bromide	do 24	Allyl iodide	do 37
Epichlorohydrin	do 24	Ethyl acetate	do 39
2-Chloroethyl ether	do 24	Methyl iodide	do 46
2-Bromoethyl ethyl ether	do 27	Methyl acetate	do 67

Ten classes of compounds are represented in this list of 18 effective fumigants, namely, 2 bromides out of 20 tested; 5 iodides out of 12 tested; the 1 epichlorohydrin tested; 2 halogenated ethers out of 5 tested; 1 halogenated ester out of 4 tested; 2 esters of halogenated

fatty acids out of 10 tested; 1 mercaptan out of 8 tested; 1 disulphide out of 2 tested; 1 thiocyanate out of 3 tested; and both [illegible] tested.

Thirteen of these 48 compounds contain halogen, and the remaining 5 contain sulphur. Three of the sulphur compounds also contain nitrogen.

PART 2.—ADDITIONAL FUMIGANTS LETHAL IN DOSAGES LESS THAN 100 MG. PER LITER

	Mg. per liter
Ethylene oxide	20
*Iso*butyl mercaptan	33
tert. Butyl chloride	34
*Iso*butyl formate	35
Allyl formate	38
Methyl formate	[illegible]
2-Chloroethyl acetate	47
n-Propyl mercaptan	[illegible]
Mesityl oxide	52
*Iso*propyl formate	53
Propylene oxide	54
Carbon tetrabromide	60
*Iso*butyl iodide	64
sec. Butyl iodide	64
Methylallyl carbinol	64
Methylisobutyl ketone	64
Methyl thiocyanate	64
tert. Amyl alcohol	65
Dimethyl *n*-propylcarbinol	66
n-Butyl mercaptan	67
Isopropyl oxide	68
*Iso*amyl formate	70
Ethyl formate	72
n-Propyl formate	72

	Mg. per liter
Diisopropylamine	72
Methyl chloroacetate	73
*Iso*butyraldehyde	79
tert. Butyl alcohol	79
Ethyl disulphide	79
Isocrotonitrile	82
n-Propyl bromide	84
Methyl *n*-butyl ketone	84
Ethyl 1-bromopropionate	84
*Iso*amyl mercaptan	84
Ethyl isobutyrate	87
*Iso*butyl acetate	87
Ethylene dibromide	87
*Iso*amyl nitrite	87
Propylene chlorohydrin	89
n-Propyl nitrate	90
Diacetyl monomethoxime	90
n-Methylhydroxylamine	90
Ethyl orthoformate	91
n-Butyl nitrite	91
Ethyl chloroacetate	93
Methyl *n*-propyl ketone	97
n-Butyl iodide	97
Ethyl thiocyanate	100

The effective compounds in part 2 of this list represent the following proportion of each class:

Three bromides out of 20 tested; 1 chloride out of 21 tested; 4 iodides out of 12 tested; 1 secondary alcohol out of 8 tested; 3 tertiary alcohols out of 11 tested; 4 ketones out of 11 tested; 1 secondary amine out of 8 tested; 2 nitrites out of 2 tested; 1 nitrile out of 3 tested; 8 formates (including 1 orthoformate) out of 9 tested; 2 acetates out of 10 tested; 1 isobutyrate out of 2 tested; 2 monochloroacetates out of 3 tested; 1 bromopropionate out of 2 tested; the 1 amine tested; the 1 hydroxylamine tested; 1 halogenated ester out of 4 tested; 2 thiocyanates out of 3 tested; 4 mercaptans out of 7 tested; 1 disulphide out of 2 tested; and both oxides tested.

Of these 48 compounds, 13 contain halogen, 8 contain nitrogen, 7 contain sulphur, 2 contain both sulphur and nitrogen, and 22 contain only carbon, hydrogen, and oxygen.

Of the 309 compounds tested, 243 were either nontoxic under the conditions of the test, or more than 101 mg. per liter was required to kill the insects.

LEAST EFFECTIVE FUMIGANTS

The following materials failed to kill any weevils at the maximum dosage of 0.5 c. c. per liter: Decane, amylene, [illegible]-tetrahydronaphthalene, 1, 2, 3-tribromobutane, hexachloroethane, iodoform, methyl alcohol, *n*-butyl alcohol, *n*-amyl alcohol, *n*-hexyl alcohol, *n*-heptyl alcohol,

n-octyl alcohol, *n*-nonyl alcohol, trimethylene chlorohydrin, β-dimethylaminoethyl alcohol, di-*n*-amyl ether, diisoamyl ether, glycol ethyl ether, chloromethyl ether, formalin, propionaldehyde, *n*-butyraldehyde, heptaldehyde, di-*n*-butyl ketone, di-*n*-amyl ketone, diacetyl, formic acid, acetic acid, chloroacetic acid, propionic acid, *n*-butyric acid, isobutyric acid, *n*-valeric acid, isovaleric acid, dimethylethylacetic acid, bromoacetyl bromide, chloroacetyl chloride, dichloroacetyl chloride, trichloroacetyl chloride, propionyl chloride, *n*-butyryl chloride, *n*-valeryl chloride, isovaleryl chloride, *n*-butyl chloroformate, isoamyl chloroformate, *n*-heptyl acetate, *sec*-octyl acetate, γ-bromopropyl acetate, ethyl cyanoacetate, methyl lactate, ethyl lactate, *n*-butyl *n*-butyrate, isobutyl *n*-butyrate, *n*-butyl *n*-valerate, *n*-propyl isovalerate, isobutyl isovalerate, isoamyl isovalerate, methyl *n*-caproate, ethyl *n*-caproate, methyl *n*-heptylate, ethyl *n*-heptylate, methyl *n*-caprylate, methyl oxalate, ethyl oxalate, isoamyl oxalate, di-*n*-propyl carbonate, di-*n*-butyl carbonate, diisoamyl carbonate, ethylidene diacetate, ethyl acetoacetate, methylamine, ethylamine, *n*-propylamine, *n*-butylamine, *n*-amylamine, dimethylamine, diisoamylamine, trimethylamine, tri-*n*-butylamine, triisoamylamine, tetramethylammonium hydroxide, chloral cyanohydrin, cyanuric acid, *n*-butanesulphochloride, and mercaptol.

These 85 nontoxic compounds represent the following proportion of the various classes: Two hydrocarbons out of 9 tested; 2 bromides out of 20 tested; 1 chloride out of 21 tested; 1 sulfide out of 12 tested; 7 primary alcohols (all straight chain) out of 12 tested; 1 chlorohydrin out of 4 tested; the 1 amino alcohol tested; 3 ethers out of 11 tested; 1 chloro ether out of 4 tested; 4 aldehydes out of 10 tested; 2 ketones out of 11 tested, 1 diketone out of 2 tested; the 2 acids tested; the 2 acid bromides and chlorides tested; 2 chloroformates out of 9 tested; 2 acetates out of 10 tested; 1 brominated ester out of 4 tested; the 1 cyanoacetate tested; both lactates tested; 2 *n*-butyrates out of 6 tested; 1 *n*-valerate out of 3 tested; 3 isovalerates out of 4 tested; both caproates tested; both heptylates tested; the 1 *n*-caprylate tested; the 3 oxalates tested; 3 carbonates out of 6 tested; the 1 diacetate tested; the 1 acetoacetate tested; 5 primary amines out of 10 tested; 2 secondary amines out of 8 tested; 3 tertiary amines out of 5 tested; the 1 tetramethylammonium derivative tested; the 1 cyanohydrin tested; the 1 cyanuric acid tested; the 1 sulphochloride tested; and the 1 miscellaneous sulphur compound tested.

CONCLUSIONS

A study of the 66 most toxic and the 85 least toxic compounds from a total of 309 tested against weevils in the presence of wheat under conditions where the compounds could come in contact with the weevils only in the vapor phase indicates:

Apparently no relation exists between the boiling point of compounds and their relative toxicity except that most compounds of high boiling point (above 150° C.) have too low a vapor pressure at room temperature (25° C.) to furnish a toxic concentration of vapor.

Branched chain radicals are more toxic than are straight chain radicals.

Chemically inert compounds, that is, paraffin hydrocarbons, have but little toxicity.

Some compounds that are highly reactive chemically, such as aldehydes, acids, and acid chlorides, are not toxic to weevils in wheat, probably because they are absorbed by the wheat and fail to reach the insects.

Compounds belonging to the following classes are the [illegible] and [illegible].

GERMINATION TESTS

METHOD

In order to determine the usefulness of a fumigant, its effect upon the germinating quality of seeds must be known. To obtain information regarding the action upon wheat germination of the various compounds tested as fumigants for the rice weevil in this investigation, careful germination tests were made upon the wheat before and after 24 hours' exposure to each fumigant. In most cases the fumigated wheat was treated with the maximum dosage of fumigant tested, namely, 0.5 c. c. per liter of space half filled with wheat, equivalent to 1.25 c. c. per kilogram of grain. These germination tests were made in duplicate upon 100 kernels of wheat by the seed testing laboratory, Bureau of Plant Industry.

EXPERIMENTAL RESULTS

The fumigants that lowered the comparative germination of wheat more than 10 per cent are given in Table 4.

TABLE 4.—*Fumigants that lower the germination of wheat 10 per cent or more of [illegible]*

Fumigant	Dosage applied	Maximum lethal dosage	Germination of fumigated wheat as percentage of check	Fumigant	Dosage applied	Maximum lethal dosage	Germination of fumigated wheat as percentage of check
	Gm. per kg. of wheat	Gm. per kg. of wheat	Per cent		Gm. per kg. of wheat	Gm. per kg. of wheat	Per cent
Allyl [illegible]	0.3	0.07	2	Chloroacetic acid	1.25	1.28	13
Do	1.7	.07	4	Bromoacetyl bromide	2.0	2.40	17
[illegible]	.6	.115	1	Chloroacetyl chloride	1.5	1.42	21
Allyl [illegible]	.3	.000	86	Dichloroacetyl chloride	1.5	1.93	83
Do	1.4	.000	27	Trichloroacetyl chloride	1.6	2.04	86
[illegible]	3.5	.90	89	n-Butyryl chloride	1.3	1.26	86
Do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2.1	.84	86	Allyl formate	1.3	.1	87
[illegible]	1.5	.08	0	Methyl chloroformate	.6	.5	88
[illegible]	.6	.47	78	Do	1.5	.5	9
Do	1.3	.47	10	Ethyl chloroformate	[illegible]	.63	63
[illegible]	.075	.05	0	n-Propyl chloroformate	1.4	1.36	13
Do	4.4	.05	0	n-Butyl chloroformate	1.3	1.33	74
[illegible]	1.1	.13	0	*Isobutyl* chloroformate	1.3	1.3	76
[illegible]	1.25	.5	89	Bromoethyl acetate	2.0	1.44	78
[illegible]	2.0	1.17	0	β-Bromoethyl acetate	2.0	1.07	87
[illegible]	1.1	1.06	87	γ-Bromopropyl acetate	.5	1.5	79
[illegible]	1.1	.43	1	Do	1.3	1.5	88
[illegible]	1.1	.96	1	Methyl monochloroacetate	.3	.16	13
[illegible]	1.45	.29	0	Do	1.3	.16	1
[illegible]	1.3	1.22	1	Ethyl monochloroacetate	.3	.23	10
[illegible] acid	.5	1.5	89	Do	1.5	.23	2
Isovaleric acid	1.2	1.17	87	*Isopropyl* monochloroacetate	.3	[illegible]	[illegible]
[illegible] acid	[illegible]	[illegible]	[illegible]				

[1] Data in this column are calculated from figures in maximum-lethal-dosage column of Table [illegible]

[2] Maximum [illegible]

[3] Maximum [illegible]

TABLE 4.—*Fumigants that lower the germination of wheat 10 per cent or more of check*—Continued

Fumigant	Dosage applied	Minimum killing dosage	Germination of fumigated wheat expressed as percentage of check	Fumigant	Dosage applied	Minimum killing dosage	Germination of fumigated wheat expressed as percentage of check
	Gm. per kg of wheat	*Gm. per kg of wheat*	*Per cent*		*Gm. per kg of wheat*	*Gm. per kg of wheat*	*Per cent*
Isopropyl monochloroacetate	1.1	[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
n-Butyl monochloroacetate	1.3	[illegible]	5	Ethyl oxalate	1.4	>[illegible] 1.25	39
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ethyl dichloroacetate	1.6	.6	22	Diisoamylamine	.95	>[illegible] .95	[illegible]
Ethyl [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Methyl [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.9	[illegible]	1	Ethyl nitrate	.9	>[illegible] 1.20	2
Ethyl [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ethyl propionate	.7	.31	80	Thiocetic acid	1.3	.56	89
Ethyl [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Isopropyl n-butyrate	1.1	>[illegible] 1.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
n-Butyl [illegible]	1.1	>[illegible] 1.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Minimum dosage tested, equivalent to 0.02 c. c. per liter or 0.05 c. c. per kilogram of wheat.
[2] Maximum dosage tested, equivalent to 0.50 c. c. per liter or 1.25 c. c. per kilogram of wheat.

DISCUSSION OF RESULTS AND CONCLUSIONS

Several of the compounds tested, for example, acids and acid chlorides, injure the germination of wheat and are not effective against weevils.

Some of the compounds that lower the percentage germination of wheat were tested in excessive doses, for instance, α-epichlorhydrin.

Only a few of the materials that hold promise as insecticides must be used cautiously upon seed grain. These are certain iodides, halogenated alcohols, epichlorohydrin, halogenated ethers, oxides, and esters of halogenated fatty acids.

The bromides, with the exception of allyl bromide, chlorides, formates, sulphides, disulphides, thiocyanates, isothiocyanates, and mercaptans, in dosages more than sufficient to kill all weevils in wheat do not injure the germination of the grain.

TESTS IN A 500-CUBIC-FOOT FUMIGATING VAULT[7]

METHOD

Of the 66 compounds that under laboratory conditions were 100 per cent toxic to the rice weevil at dosages less than 100 mg. per liter or 6.24 pounds per 1,000 cubic feet, only a few possess the desirable

[7] Detailed accounts of the tests with the most promising of the fumigants and the method for the calculating [illegible]

[illegible], R. T., and Roark, R. C. [illegible] MATTOX, and [illegible] A NEW NONINFLAMMABLE, NONEXPLOSIVE FUMIGANT. [illegible] Rubber Age 29: [illegible] 1931.

[illegible] and Roark, R. C. [illegible] ETHYLENE DICHLORIDE-CARBON TETRACHLORIDE MIXTURES AS GRAIN FUMIGANTS. Indus. and Engin. Chem. 20: 380-382. 1928.

[illegible] and Roark, R. C. [illegible] AS A FUMIGANT. Indus. and Engin. Chem. 20: 807. 1928.

Roark, R. C., and Cotton, R. T. [illegible] TESTS WITH CERTAIN ALIPHATIC CHLORIDES. Jour. Econ. Ent. 21: 36-42. 1928.

[illegible] and Cotton, R. T. [illegible] ACTION OF SOME ESTERS OF HALOGENATED FATTY ACIDS IN THE VAPOR PHASE. Indus. and Engin. Chem. 20: 712-714. 1928.

qualities of cheapness, effectiveness, commercial availability, and freedom from fire hazard and injurious effect upon man or merchandise.

Seventeen of the compounds that possess some or all of these qualifications were selected as worthy of further testing. A series of experiments with these was conducted in a commercial-type fumigating vault which was of very tight construction and had a capacity of 500 cubic feet. The fumigant to be tested was poured through a trap door in the top of the vault into a shallow trough suspended close to the ceiling. The vault was then closed for 24 hours. The insects used were the larvae of the clothes moth (*Tineola biselliella*), of the black carpet beetle (*Attagenus piceus*), and of the furniture beetle (*Anthrenus vorax*), all species highly resistant to fumigants. The larvae were placed in cotton-stoppered vials and buried in pieces of overstuffed furniture. In all tests 20 specimens of the clothes moth and 50 specimens of each of the other species were used.

In addition to these tests comparative tests with carbon tetrachloride and carbon disulphide were made.

EXPERIMENTAL RESULTS

Table 5 contains data indicating the relative toxicity of the various compounds or mixtures of compounds tested. With the exception of carbon disulphide and ethylene oxide, the vapors of the compounds, or a mixture of a compound and carbon tetrachloride, used in the experiment are nonflammable and nonexplosive when heated to 122° F. and may therefore be considered as free from fire hazard.

TABLE 5.—*Results of fumigation tests on insects in a 500-cubic-foot vault*

Class	Fumigant				Temperature	Minimum lethal dosage for an exposure of 24 hours
	Compound	Parts by volume	Compound	Parts by volume		
					° F.	*Pounds for 1,000 cubic feet*
Chlorides	Carbon tetrachloride				83	30
	do	1	Ethylene dichloride	3	85	6
	do	1	do	3	65	12
	do	7	*tert.*-Butyl chloride	3	83	12
	do				83	12
	Trichloroethylene				85	30
	Tetrachloroethylene				85	5
Iodides	Carbon tetrachloride	3	Ethyl iodide	1	85	20
Alcohols	do	7	*tert.*-Butyl alcohol	3	75	1
Oxides	Ethylene oxide				85	11
Formates	Carbon tetrachloride	7	*n*-Propyl formate	3	85	14
	do	3	*Iso*propyl formate	1	85	8
	do	3	*sec.*-Butyl formate	2	85	9
	do	3	*Iso*butyl formate	2	85	7
	do	3	*Iso*amyl formate	2	83	15
	do	7	*Iso*propyl acetate	3	83	1
Acetates	do				83	2
Monochloroacetates	Methyl monochloroacetate				83	1½
	Ethyl monochloroacetate				83	30+
	*Iso*propyl monochloroacetate				80	1¼
Carbonates	Carbon tetrachloride	1	Diethyl carbonate	1		
Disulphides	Carbon disulphide					

DISCUSSION OF RESULTS AND CONCLUSIONS

The data in Table 5 show that several of the compounds are sufficiently toxic to be of value as fumigants. Ethylene oxide and methyl monochloroacetate appear to be the most toxic of the compounds tested, and when used in a tight vault compare favorably in toxicity with carbon disulphide. Others somewhat less toxic have advantages that compensate for the lower toxicity and enhance their value for fumigation of some types. Some of the advantages and limitations of these materials are discussed below.

CHLORIDES

The chlorides as a group are cheap, commercially available in large quantities, not highly toxic to man, and not readily flammable. They possess pleasant odors, and do not affect the germination of wheat. Of the several chlorides tested on a large scale, ethylene dichloride in a mixture of 3 volumes to 1 volume of carbon tetrachloride appears to be the most promising as a general fumigant. At 85° F. or over, a complete kill is obtained with 6 pounds of the mixture per 1,000 cubic feet of space. At lower temperatures a somewhat larger dose is required to give equally good results. The 3 to 1 mixture is nonflammable, nontoxic to man, and harmless to fabrics and furniture. It does not affect the germinating qualities of wheat, but gives to foodstuffs rich in oil a characteristic sweetish taste, which they are likely to retain for some time. In Industrial and Engineering Chemistry for February, 1930, ethylene dichloride in tank cars is quoted at 8 cents per pound, f. o. b.

Although more toxic than ethylene dichloride, *tert.*-butyl chloride requires a larger proportion of carbon tetrachloride to render it free from fire hazard, and it can not be used in metal-lined vaults because it attacks the metal.

Trichloroethylene is nonflammable and in the large scale tests proved to be about two and a half times as toxic as carbon tetrachloride at 80° F. or over. It should be valuable for combining with more toxic compounds to reduce the fire hazard.

Tetrachloroethylene, also nonflammable, is about as toxic as carbon tetrachloride.

IODIDES

Ethyl iodide, the only iodide tested on a large scale, is highly toxic, but owing to its high cost and the improbability of its being produced cheaply in the near future, it can not be considered a practical fumigant.

ALCOHOLS

Tertiary butyl alcohol is the most toxic of the alcohols tested. As the vapors are flammable, however, such a large proportion of carbon tetrachloride must be added to remove the fire hazard that the toxicity of the resulting mixture is reduced to a prohibitive extent.

OXIDES

Ethylene oxide shows promise of being an excellent all-purpose fumigant. A gas at ordinary temperatures, it is put up in liquid form under pressure. The gas is almost odorless, and so far as known has no injurious effect upon merchandise. Owing to its low boiling point, 10.7° C., it is effective at comparatively low tempera-

tures, a feature that greatly enhances its value. The vapors are flammable and in high concentrations produce anaesthesia in man. In a concentration of 1 pound per 1,000 cubic feet, however, the fire and human hazards are negligible. The 1930 price of ethylene oxide is about $2 a pound in small quantities or 75 cents a pound in large quantities. It could probably be made to sell in large quantities at about 40 cents a pound.

FORMATES

The vapors of the lower alkyl formates are highly toxic to insects, and by admixture with carbon tetrachloride, formates that boil above 70° C. can be made free from fire hazard. The vapors are not injurious to the germinating power of grain and seem well adapted for the fumigation of foodstuffs. The esters of formic acid are now commercially available. When these formates are used as fumigants, a temperature of 75° F. or more is essential to obtain the best results.

ACETATES

Tests with *iso*propyl acetate indicated that so large a proportion of carbon tetrachloride must be added to obtain a mixture free from fire hazard that the effectiveness is reduced too low for practical purposes.

MONOCHLOROACETATES

The monochloroacetates tested on a large scale are highly toxic at 80° F. and above. Owing to their high boiling point they are not efficient at low temperatures. Their vapors have a slightly irritating effect upon the eyes, but their lachrymatory power is much less than that of chloropicrin. Very little is known regarding the physiological action of monochloroacetic acid and its esters. The vapors of these esters, heated to 122° in admixture with air in a box will not propagate a flame when sparked and therefore may be said to be free from fire hazard. In small lots ethyl monochloroacetate has been quoted at from $1 to $1.50 a pound. It is believed that it could be manufactured in moderate quantities to sell at not more than 30 cents a pound. The methyl and *iso*propyl esters could probably be made to sell for not more than 50 cents a pound.

The results of germination tests on wheat fumigated with these monochloroacetates indicate that they have an injurious effect upon the germination.

CARBONATES

When mixed with a quantity of carbon tetrachloride sufficient to remove the fire hazard the vapors of diethyl carbonate are not toxic enough to be of commercial value.

SUMMARY

Three hundred and nine aliphatic compounds were tested against the rice weevil in ½-liter Erlenmeyer flasks half filled with wheat. Sixty-six of these compounds were lethal after an exposure of 24 hours, in dosages less than 100 mg. per liter or 6.24 pounds per 1,000 cubic feet, 18 of these being lethal in the minimum dosage tried, 0.02 c. c. per liter (1 to 4 pounds per 1,000 cubic feet).

The compounds showing the greatest toxicity are in the following classes: Iodides, bromides, mercaptans, thiocyanates, isothiocyanates,

disulphides, oxides, epichlorohydrin, halogenated ethers, halogenated esters, and formates.

An analysis of the results obtained with the 66 most toxic and the 85 least toxic compounds tested indicates that there is no apparent relation between the boiling point of compounds and their relative toxicity, except that most compounds having a high boiling point (above 150° C.) have too low a vapor pressure at room temperature to furnish a toxic concentration; that branched chain radicals are more toxic than are straight chain radicals; that compounds which are inert chemically have little toxicity; and that some compounds highly reactive chemically do not kill weevils in wheat, probably because they are absorbed by the wheat and fail to reach the insects.

Germination tests with wheat showed that the chlorides, formates, sulphides, disulphides, thiocyanates, *iso*thiocyanates, and mercaptans in dosages more than sufficient to kill weevils do not injure the germination of the grain. The iodides, halogenated alcohols, epichlorohydrin, halogenated ethers, oxides, and esters of halogenated fatty acids are injurious to the germination of wheat and should be used with caution.

Many effective compounds are unavailable commercially or are too costly to be of practical value. Seventeen compounds showing promise of commercial value were tested in a 500-cubic-foot fumigation vault. Two of these, ethylene oxide and methyl monochloroacetate, were shown to be slightly more toxic than carbon disulphide. They were lethal at a dosage of 1 pound per 1,000 cubic feet. The ethyl and *iso*propyl esters of monochloroacetic acid were only slightly less toxic.

Ethylene dichloride in admixture with carbon tetrachloride in the ratio of 3 parts to 1 by volume was lethal at a dosage of 6 pounds per 1,000 cubic feet. Because of its low cost, effectiveness, and lack of fire hazard and toxicity to human beings, ethylene dichloride should be a useful fumigant.

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